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14. ABSTRACT

The entire fleet of Boeing Model 702 geosynchronous satellites has suffered from a similar fate: degradation of the solar cell panels. Mirrors flank both sides of the solar cell panels. Degradation, sometimes sudden and stepwise, shortens the lifetime of the solar cells. We suggest that space environment effects play an important role in damaging the solar cells. As a cornerstone in this idea, we expound a theorem that high reflectivity reduces photoemission. With little or no photoemission, mirrors often charge to minus kilovolts in eclipse as well as in sunlight, whenever the space plasma is hot enough. Since the rest of the solar panel does not have this mirror property, differential charging between the mirrors and the rest of the solar panel occurs during eclipse exits. We show the charging data obtained during an eclipse exit on LANL-97A satellite for supporting the idea of differential charging. Finally, we recommend this important mirror charging property to be taken in account in future solar panel designs and in commercial products of spacecraft charging computer codes.

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ELECTROSTATIC CHARGING OF MIRRORS IN SPACE: A PLAUSIBLE CAUSE OF SOLAR PANEL ANOMALIES ON SATELLITES

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ABSTRACT

The entire fleet of Boeing Model 702 geosynchronous satellites has suffered from a similar fate: degradation of the solar cell panels. Mirrors flank both sides of the solar cell panels. Degradation, sometimes sudden and stepwise, shortens the lifetime of the solar cells. We suggest that space environment effects play an important role in damaging the solar cells. As a cornerstone in this idea, we expound a theorem that high reflectivity reduces photoemission. With little or no photoemission, mirrors often charge to minus kilovolts in eclipse as well as in sunlight, whenever the space plasma is hot enough. Since the rest of the solar panel does not have this mirror property, differential charging between the mirrors and the rest of the solar panel occurs during eclipse exits. We show the charging data obtained during an eclipse exit on LANL-97A satellite for supporting the idea of differential charging. Finally, we recommend this important mirror charging property to be taken in account in future solar panel designs and in commercial products of spacecraft charging computer codes.

INTRODUCTION

This work is motivated by the news [1] that all Boeing "Model 702" geosynchronous satellites have suffered from fast degradation of their solar cells. In particular, PanAm's PAS-7, with solar panels of the same design, suffered from a 25% degradation of its solar cell efficiency, when the satellite came out of its eclipse, Sept 6, 2001 [2]. These satellites feature long solar panels flanked by reflectors (mirrors) on both sides [Figure 1]. The purpose of using the mirrors is to enhance the efficiency of sunlight collection on the solar cells. Boeing has now decided to withdraw the mirrors from all future 702 satellites. Motivated by this news, we wish to offer a plausible cause. The cause is built on a cornerstone, which we call mirror charging. We will build this cornerstone in this paper. While the engineering details of the 702 satellites are unknown, we do not attempt to justify our theory with the actual cases. The true cause may never be known.

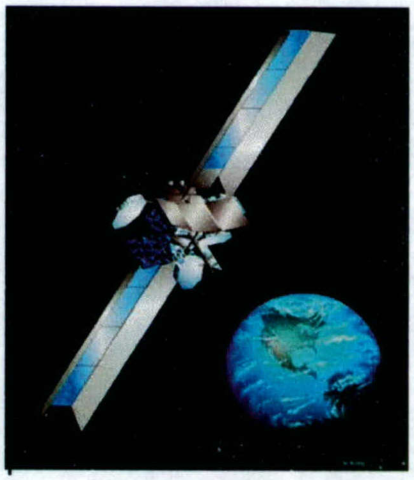

Figure 1. Boeing model 702 satellite with solar panels flanked by mirrors [3]

PHOTOEMISSION FROM MIRRORS

Photoelectrons from surfaces are generated by photons impacting the surface. According to Einstein, a photon can generate a photoelectron of energy E, only if the photon energy $h\nu$ exceeds the work function W.

$$h\nu = E + W \tag{1}$$

With a high reflectance surface, the reflected photons are almost as intense as the incoming ones, implying little energy is lost in the reflection. As a result, little energy is imparted to the surface material for generating photoelectrons. The most important spectral line in sunlight is the Lyman α, which has $h\nu$ =10.2 eV [4]. The work function of typical spacecraft surfaces is about W = 5 eV [5]. If, for example, only 48% of the sunlight photon energy $h\nu$ is available, there would not be enough energy to generate photoelectrons. The photoelectron yield Y per unit incident photon is related to the photoelectron yield γ per unit absorbed photon by the relation [6,7]:

$$Y = \gamma(1 - R) \tag{2}$$

where R is the reflectance. The depth of reflectance is shallower than the depths of ionization, photoemission and attenuation [8].

Modern mirrors in space are made of aluminum. The reflectance R of highly polished aluminum surfaces is about 90% in the Lyman α wavelength region [4]. With a commercial space mirror coating [9], the reflectance R is in the upper 80%. In view of such high reflectance R, we conjecture that only little photoemission is generated from high reflectance surfaces in space.

MIRROR CHARGING

Surfaces often charge to high voltages (up to hundreds or thousands of negative Volts) in hot plasmas at geosynchronous altitudes in eclipse. Charging occurs if the space plasma electron temperature exceeds a critical temperature [10]. The exact potential is controlled by a current balance equation [11]:

$$I_e(\phi)\left[1 - I_s(\phi) - I_b(\phi)\right] - I_i(\phi) = I_{ph}(\phi) \tag{3}$$

where I_e is the incoming electron current, I_s is the secondary electron current, I_b the backscattered electron current, I_{ph} the outgoing photoelectron current, and ϕ the surface potential.

The photoemission current I_{ph} from most surfaces usually exceeds the incoming plasma electron current I_e. Therefore, no charging to negative potentials is expected in sunlight for most surfaces. Charging of conducting surfaces in sunlight is usually to a few positive Volts only because photoelectrons have only a few eV in energy E [12].

However, there is only little photoemission from mirrors. A mirror behaves in sunlight as if it is almost in eclipse, as far as charging is concerned. Therefore, we conjecture that, mirrors charge to negative potentials no matter if they are in sunlight or in eclipse.

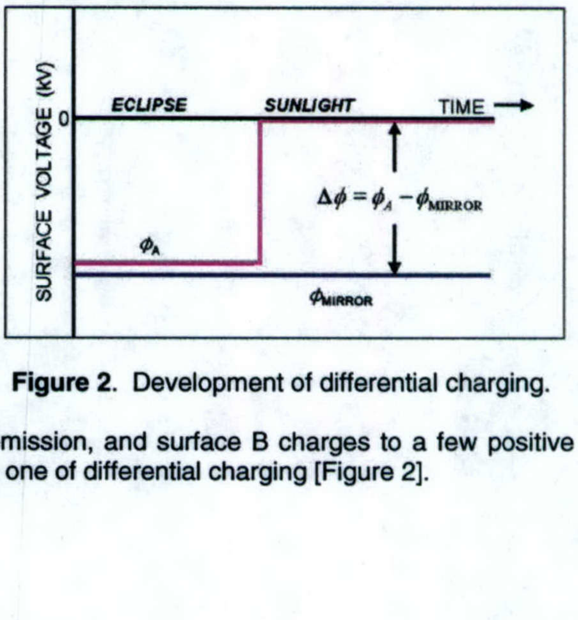

Figure 2. Development of differential charging.

As an example, suppose we consider two surfaces side by side on a geosynchronous spacecraft. Suppose they have about the same surface properties except one (A) is a mirror while the other (B) is not. During eclipse passage, there is no photoemission and therefore both behave similarly, viz., charging to negative kilovolts. Upon eclipse exit, sunlight shines, surface A continues to charge to high negative volts because A emits little or no photoemission, and surface B charges to a few positive Volts as a result of photoemission. The situation becomes one of differential charging [Figure 2].

Furthermore, it is well known that hot electrons of the space plasma at the geosynchronous midnight region convect eastwards to the morning sector as a result of cross-geomagnetic tail electric field and curvature drift by the Earth's magnetic field. A geosynchronous satellite orbits the Earth in the same direction of the Earth's rotation, viz., eastwards. Therefore, upon eclipse exit, the satellite may encounter hot electrons. Spacecraft charging occurs if the plasma electrons are hotter than a critical temperature, typically 1 to 3 keV depending on the surface material [10]. Indeed, statistics show that spacecraft charging to high negative voltages is more likely in the morning sector.

SPACE HAZARD

Differential charging may cause adverse effects. Sudden development of differential charging is potentially hazardous. Suppose two neighboring surfaces (a mirror and a non-mirror) develop a potential difference of about a kilovolt. There can be two adverse effects; (1) a discharge between them may suddenly occur, and (2) sputtering may cause slow degradation of the mirror, reducing its efficiency. A discharge can cause a sudden and stepwise degradation to the solar panel system. Sputtering may pose a long term effect, viz., slow degradation of the system, resulting in shortening the expected lifetime of the solar panel system.

The PAS-7 satellite did not have instruments onboard to measure charging or the hot electrons. The nearest satellite that had this capability was the Los Alamos National Laboratory satellite LANL-97A. Indeed, LANL-07A showed charging to $\phi = -3$ kV during the entire eclipse passage in early morning of Sep 6, 2001 [Figure 3]. The charging level ϕ dropped to $\phi = 0$ abruptly upon eclipse exit. Although PAS-7 had no such measurement capabilities, we infer that PAS-7 might behave likewise, viz.,, charging to about $\phi = -3$ kV during the eclipse passage. Upon the PAS-7 eclipse exit, ϕ might drop to 0 abruptly. However, the PAS-7 mirrors probably continued to behave almost as if in eclipse, because they emitted little or no photoelectron current no matter if in eclipse or in sunlight. As a result, differential charging of the order of kV might emerged abruptly upon eclipse exit in the morning sector.

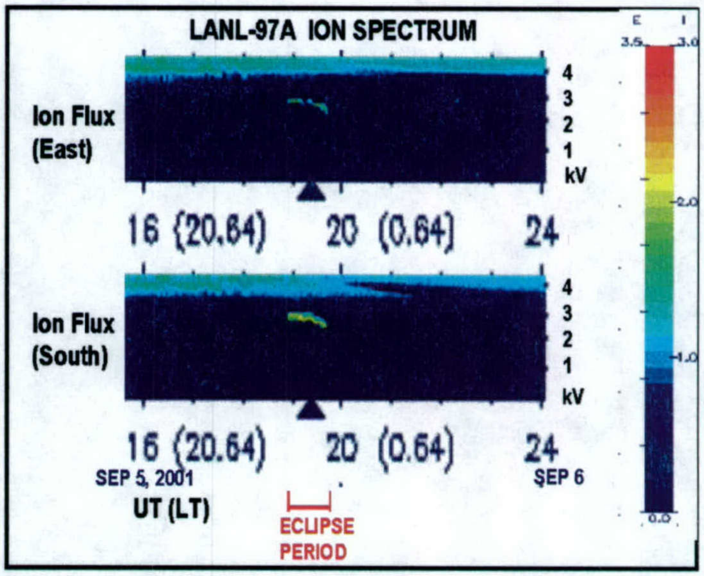

Figure 3. Eclipse charging of LANL 97-A satellite to –3 kV.

CONCLUSION

All Boeing model 702 satellite solar panels flanked by mirrors have experienced gradual or sudden degradations. The true cause is unknown and Boeing has ceased to use this design. We have offered a new concept – mirror charging. We conjecture that mirrors do not generate much photoemission. Accordingly, they charge to high negative voltages no matter if in eclipse or in sunlight. When a mirror and a neighboring non-mirror surface come out from eclipse, differential charging up to kV may occur, depending on the temperature of the space plasma. The effects of differential charging are potential hazards of discharges between surfaces and gradual degradation of the solar panel system due to sputtering by keV ions.

We suggest that the concept of mirror charging be studied in the laboratory and in space. In laboratory studies, care must be taken to separate the photoemissions from mirror samples and from the vacuum chamber walls. In space studies, measurements on differential charging should be made. Finally, we suggest that mirror charging be incorporated into commercial codes of spacecraft charging.

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